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Study on the potential of cultivated land quality improvement based on a geological detector

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The restrictive factors of cultivated land are key to the improvement of cultivated land quality, scientific implementation of the land consolidation projects, and the efficiency of remediation. On the basis of the provincial plots of cultivated land quality in Shaanxi Province, this paper analysed the improvement potential of cultivated land quality from the perspective of restrictive factors. First, the potential exponential model was used to determine the distribution of various combinations of restrictive factors at the provincial scale. Second, a geological detector was used to determine the influences of different combinations of restrictive factors on cultivated land quality. Finally, through the investigation of cultivated land consolidation projects that have been implemented in the study area, the improvement potential level of different combinations of restrictive factors was determined. The degree of influence of the single restrictive factor or combinations of restrictive factors on the quality of cultivated land was improved, and the difference of the quality of cultivated land in different index areas could be revealed as well. The results showed that there were 12 single-factor restrictions and 34 double-factor restrictions. The area under single-factor restrictions reached 76.77% of the total land. The quality of cultivated land in the southern and central areas of Shaanxi Province was relatively good. The quality of cultivated land in the northern region was under significant influence of restrictive factors whereas that in southern and middle areas was less affected. From the perspective of improvement potential of restrictive factors, Shaanxi was relatively low with huge internal diversity, whereas the improvement potential in northern Shaanxi had huge advantage.

KEYWORDS

combination of restrictive factors, cultivated land, land consolidation, soil restrictive factors

1 | INTRODUCTION

The overall quality of cultivated land in China is relatively low; land pollution is serious, and the obstacles are many (Chen et al., 2011). Due to acceleration of the urbanization process, urban land is expanding, and the amount of cultivated land is decreasing; therefore, the quality of cultivated land is becoming increasingly important to ensure food security under the premise of increasing demand for grain (Xu, Lu, Zhang, Li, & Duan, 2016). With the implementation of land development projects, the reserve resources of cultivated land are gradually being reduced, and the quality of existing cultivated land will be the focus of future work on cultivated land protection. The quality factor is the main reason to improve cultivated land. Studies of cultivated land quality from the perspective of restrictive factors can provide new ideas for land consolidation projects and provide new theories for protection of cultivated land.

For a long time, research on the evaluation of cultivated land quality has been based on land consolidation projects, with an emphasis on evaluating the consolidation potential and effects from the view of cultivated land quality improvement (Crecente, Alvarez, & Fra, 2002; Yang, Xie, Liao, Pan, & Zhu, 2013; Yu, Feng, Che, et al., 2010). The evaluation methods of cultivated land quality differ from the evaluation purpose. At present, the evaluation of cultivated land quality includes agricultural production capacity, cultivated land potential, adaptability, and sustainability (Fu & Bai, 2015). In studies of land consolidation, the evaluation of cultivated land quality in the land remediation project area is a hot spot of research (Kuang, Ye, Zhao, Guo, & Xie, 2016; Ma et al., 2013; Zhang, Zhao, Tian, Qiu, & Shi, 2017). There are multiple research efforts on the basis of the revaluation method of improving cultivated land quality after cultivated land consolidation, and the main difference in these methods is the revaluation index system. Most of the methods are based on the classification of agricultural land. They start with the analysis of the influence of land consolidation projects on the cultivated land quality, supplemented with the natural quality, production conditions, and correction factors corresponding to the consolidation projects and the build evaluation system, with a final goal of determining the improvement interests of cultivated land generated from land consolidation projects through comparing the changes of cultivated land quality classification (Chen, Gao, & Zhao, 2016; Xu, Jin, Wu, & Zhou, 2015). Some researchers use mathematical methods to explore the influence of nature and management factors on cultivated land productivity. By calculating the grain production in the study area, the production capacity, actual production capacity, and grain yield potential can be analysed and compared as the standard of the potential of cultivated land quality improvement (Wang, Xu, Li, & Chen, 2013). It can be seen that the existing evaluations of cultivated land quality mainly serve a specific project, and there are few studies on cultivating quality limitation factors from the cultivated land quality evaluations (Jiang et al., 2014; Tong, Hu, & Yang, 2015).

At present, research on cultivated land restrictive factors can be divided into two aspects. The first aspect is the restrictive factor analysis on the basis of cultivated land quality classification. Scholars directly used the qualitative analysis method to analyse the key restrictive factors affecting the quality of the cultivated land in different standard farming systems by using the factors of the agricultural land classification as the restrictive factors (Li, Xu, & Guo, 2014). Other scholars have comprehensively ranked the classification factors and determined the leading restrictive factors that influence the cultivated land quality by the area of different combinations (Ye et al., 2016). Although the method can be linked with cultivated land division, it does not quantify the impact of various combinations of restrictions on the quality of cultivated land.

The second aspect is analysis on the basis of land consolidation projects. It considers the impacts of restrictive factors, supplement factors such as field sticks, field regulations, and cultivated land convenience by the angle of land consolidation projects, and then evaluates the cultivated land quality (Chen, Yu, Zhang, & Chen, 2016; Cheng et al., 2016). This method fully reflects the impact of land remediation on the quality of cultivated land, but new subjective factors are included. The evaluation results cannot be compared with the results of the original classification; new subjective quantitative factors are added to it (Gao, Wu, Chen, & Zhou, 2016). The improvement of the restrictive factors directly affects the improvement of the quality of cultivated land. Some scholars have pointed out that in areas with single restrictive factors, the improvement of cultivated land quality is not significant and there are some limitations. In a multifactor restricted area, the improvement of the restrictive factors can often directly improve the quality of cultivated land (Ye, Wu, Zhao, Wei, & Gao, 2015). Therefore, determining how to quantify the impact of single-factor limitations and multifactor limitations on the quality of cultivated land is particularly important.

The key to improving the quality of cultivated land is analysing the restrictive factors of cultivated land quality and finding the bottleneck of cultivated land quality improvement. The factors of cultivated land quality are the natural endowments of cultivated land resources, which reflect the quality of cultivated land (Zhang, Jiang, Zhou, Sun, & Wang, 2013).

In this paper, taking Shaanxi Province as an example, on the basis of the provincial plots of cultivated land quality data in Shaanxi Province, as well as the existing classification factors, the influence index of cultivated land quality was determined through the potential index model. The influence of various restrictive factors in Shaanxi Province and the seven index areas was based on the degree of influence of the combination of factors of cultivated land quality on the quality differences of cultivated land and the influence of the restrictive factors in the province. The improvement measures for cultivated land improvement projects in the study area aimed to investigate the effects of restrictive different factors on land quality, and finally, the potential of cultivated land quality improvement in Shaanxi Province was determined.

2 | MATERIALS AND METHODS

2.1 | Research area overview

Shaanxi Province is located in the hinterlands of Central China, between 105°29′ and 111°15′ longitude and 31°42′ and 39°35′ north latitude. It meets Inner Mongolia in the north, Gansu and Ningxia in the west, Sichuan and Chongqing in the south, and Hubei and Henan in the south-east and Shanxi Province in the east. The overall terrain is high in the north and south and low in the middle. Shaanxi stretches across the Yellow River and the Yangtze River. The annual average number of sunshine hours is 1,350–2,926 hr, the annual average temperature in the province is 6–16 °C, and the annual rainfall is between 330 and 1,250 mm, with an average annual value of 653 mm. According to the second national soil survey (1979–1985), the distribution of loess soil, yellow-brown soil, and coarse soil is widespread.

On the basis of the division of the national secondary index areas, Shaanxi Province is divided into seven three-level index areas (Figure 1). According to data on land use change in Shaanxi Province in 2014, the total land area of Shaanxi Province is 2,056,239,000 ha, of which 399,825,000 ha is cultivated land. The abbreviations of the seven index areas are shown in Table 1.

2.2 | Data sources

The data used in this paper were derived from the 2014 Shaanxi Arable Land Classification Database, which is confidential without the permission of the government.

3 | RESEARCH METHODS

3.1 | Geodetector

Geographic detectors are most commonly used in the detection of disease risk (Wang, Li, & Christakos, 2010), and they can detect spatial pattern, genesis, and the mechanistic factors, making them a powerful tool for spatial differentiation analysis (Wang, Zhang, & Fu, 2016). The advantages of geodetectors compared with other spatial analysis methods are mainly reflected in two aspects. First, the data foundation can be either quantitative or qualitative. Second, the method can detect the influence of two factors dependent on the degree of the

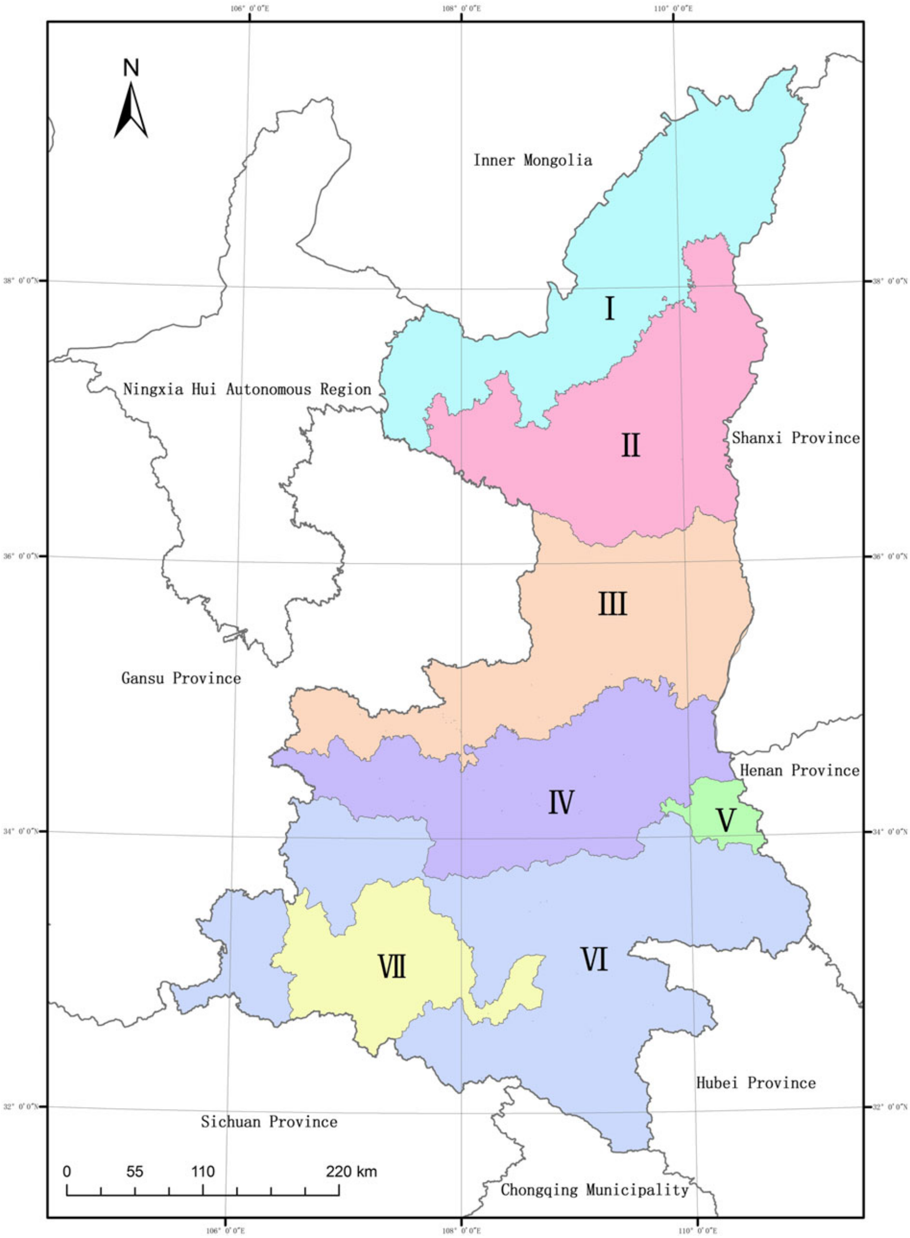

FIGURE 1 Administrative divisions in Shaanxi Province [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Abbreviations of the seven index areas

Area	Index area name
I	The sandy area along the Great Wall of northern Shaanxi
II	Loess hilly and gully region of northern Shaanxi
III	Weibei Loess Plateau area
IV	Guanzhong Weihe River Plain area
V	Shangluo mountain hilly area
VI	Middle and high mountain area of southern Shaanxi
VII	Low mountain plain district of southern Shaanxi

variables (Wang & Xu, 2017). The output results include factor detection, interactive detection, risk detection, and ecological detection. Factor detection is used to monitor whether a factor is the spatial differentiation of a certain target value; interactive detection is used to characterize the interaction of factors with each other after a degree of spatial differentiation is enhanced or weakened; ecological detection is used to compare the effects of factor interactions on the spatial differentiation of indicators, which are generally represented by *F* statistics; and risk detection is used to detect whether there are significant differences in the corresponding index values of different types of factors, which are generally represented by *T* statistics (Zhu, Liu, & Tao, 2015). The core technique of the method is to compare the total variance of the index on different categories and the total variance of the index over the entire research area, using the following formula (Wei, Li, & Liu, 2014):

$$q_{x,y} = 1 - \frac{1}{n\sigma_y^2} \sum_{i=1}^{m} n_{x,i} \sigma_{y_{x,i}}^2, \quad (1)$$

where y is the dependent variable, x is the independent variable, $q_{x,y}$ is the degree of interpretation of y by x, n is the whole sample number, σ^2

is variance, m is the number of factors of one category, $n_{x,i}$ is the sample numbers of x in i categories, and the value range of $q_{x,y}$ is [0, 1]. When $q_{x,y}$ = 0, it means that the spatial distribution of cultivated land quality is not influenced by restrictive factors. When $q_{x,y}$ increases, the influence of restrictive factors also increases, which could explain the spatial differential characteristics of cultivated land quality.

3.2 | Natural grade improvement potential model of cultivated land quality

The natural potential index model is based on the natural quality of agricultural land. It compares the actual value with the maximum potential value of the evaluation index affecting cultivated land quality, and the percentage of the difference makes the natural potential index (Sun, Wu, Hu, Zhou, & Ma, 2013). The formulas used are as follows:

$$p_{ik} = \frac{(R_{ik} - r_{ik})}{R_{ik}} \times 100\%, \quad (2)$$

$$R_{ik} = \frac{\sum_{j=1}^{j} w_{jk} \cdot F_{ijk} \cdot \alpha_j \cdot \beta_j}{100}, \quad (3)$$

$$r_{ik} = \frac{\sum_{j=1}^{j} w_{jk} \cdot f_{ijk} \cdot \alpha_j \cdot \beta_j}{100}, \quad (4)$$

where P_{ik} is the natural potential index of the kth factor in the ith unit, R_{ik} is the largest contributing value of the kth factor in the ith unit, r_{ik} is the actual contribution value of the kth factor in the ith unit, W_{jk} is the weight of the jth assigned plant of the kth factor, f_{ijk} is the actual quality value of the jth assigned plant of the kth factor in the ith unit, F_{ijk} is the largest quality value of the jth assigned plant of the kth factor in the ith unit, a_j is the light-temperature potential productivity index of the jth plant, β_j is the yield ratio of the jth plant, and k is the number of the factor. According to the above indicators, the natural potential index P can be calculated. The greater the value, the greater the potential to increase land quality.

4 | RESULTS

4.1 | Recognition of the restrictive factors of cultivated land

The quality of cultivated land is a comprehensive representation of natural utility and economic attributes. In this paper, on the basis of the cultivated land quality classification results, the potential quality of cultivated land was studied to ultimately determine the restrictive factors of the seven index areas in Shaanxi Province (Table 2). The factors affecting land quality stipulated in the Land Rendering Project Research Plan (TD/T1013-2013) were accepted as necessary factors. The indicators were designated corresponding numbers as follows: terrain slope (87), effective thickness of soil layer (88), surface soil texture (89), soil salination (90), soil organic matter content (91), fixed rate of irrigation (92), irrigation water source (93), degree of soil erosion (94), soil slope configuration (95), drainage condition (96), degree of outcropping (97), and soil pH (98).

4.2 | Analysis of the restrictive factors of cultivated land

This study investigated the improvement potential of the restrictive factors of cultivated land in Shaanxi, and the results show that there are 46 combinations of restrictive factors, among which 12 are single-factor restrictions and 34 are double-factor restrictions. Some of the restrictions accounted for a large proportion of cultivated land; the distribution is presented in Table 3. Spatial distribution of the restrictive factors in the seven indices is shown in Table 4.

Single-factor restriction distributes widely in the cultivated land of Shaanxi Province (Table 3). The improvement measures aiming at single-factor restrictions are beneficial for the overall quality of the cultivated land. There are 12 single-factor restrictions, reaching 3,069,331.68 hm^2, which accounts for 76.77% of the total cultivated land. The restrictive factors are mainly terrain, thickness of soil layer, and soil organic matter. The cultivated land under restriction of terrain occurs over 1,031,793.3 hm^2, representing about a quarter of all

TABLE 2 Restrictive factors in seven indicator areas in Shaanxi Province

	I	II	III	IV	V	VI	VII
Terrain slope		√	√	√	√	√	
Effective thickness of soil layer	√	√	√	√	√	√	√
Surface soil texture	√	√		√	√	√	√
Soil salinity	√			√			
Soil organic matter content	√	√	√	√	√	√	√
Irrigation guarantee rate	√	√		√	√		√
Irrigation water source	√		√	√			
Degree of soil erosion		√	√				
Soil slope configuration			√				√
Drainage condition				√			
Degree of outcropping					√	√	
Soil pH						√	√

Note. Due to the limited layout, the restrictive factor scores are omitted, and the ranges and scores of the factors are referred for "agricultural land quality classification rules" and the latest agricultural land classification in the county (city) where the study area is located.

TABLE 3 Restrictive factors distribution in Shaanxi Province

Number	Restrictive factor type	I	II	III	IV	V	VI	VII	Area (acre)	Percentage (%)
1	87		396,633.65	80,929.78	67,503.48	13,012.75		473,713.64	1,031,793.3	25.81
2	88	51,782.93	104,391.25	57,184.74	235,352.13	22,601.05	102,423.18	58,051.96	631,787.24	15.80
3	91	87,289.73	9,419.04	26,754.49	409,852.34	180.31	30,724.82	28,555.67	592,776.41	14.83
4	92	732.93	35,816.48	318,455.26	28,287	8,130.06	66,823.59		458,245.32	11.46
5	9293	312,965.73							312,965.73	7.83
6	93				224,803.52				224,803.52	5.62
6	9192	603.38		55,402.74	53,519.92	154.19	1,040.68		110,720.91	2.77
8	94		21,235.41	36,924.88					58,160.29	1.45
9	8891	2,791.10		2.41	32,447.64		4,340.20	10,239.20	49,820.55	1.25
10	89				9,090.20	7.79	5,518.47	14,615.37	29,231.82	0.73
11	8892	1,728.35	7.78	669.51	25,429.42	607.17			28,442.23	0.71

TABLE 4 The distribution of restrictive factors in seven indicator areas in Shaanxi Province

	Secondary restrictive area				
Name	Single-factor area	Area	Combination-factor area	Area	The leading restrictive factor
I	91	87,289.73	9293	312,965.73	9293
	88	51,782.93	8891	2,791.10	91
	90	734.16	8892	1,728.35	88
II	87	396,633.65	8794	18,006.62	87
	88	104,391.25	8889	57.29	88
	92	35,816.48	8791	46.52	92
III	92	318,455.26	9192	55,402.74	92
	87	80,929.78	8894	18,949.22	87
	88	57,184.74	9495	1,477.36	88
IV	91	409,852.34	9192	53,519.92	91
	88	235,352.13	8891	32,447.64	88
	93	224,803.52	8892	25,429.42	93
V	88	22,601.05	8892	607.17	88
	87	13,012.75	8889	426.31	87
	92	8,130.06	9192	154.19	92
VI	88	102,423.18	9295	18,559.35	88
	92	66,823.59	8895	12,559.76	92
	91	30,724.82	9195	11,313.77	91
VII	87	473,713.64	8891	10,239.20	87
	88	58,051.96	8791	8,914.38	88
	91	28,555.67	8991	3,749.05	91

cultivated land in Shaanxi. Except for the sandy area along the Great Wall of northern Shaanxi and the low mountain plain district of southern Shaanxi, there exists terrain, which is limited in other index areas. The distribution spreads the widest in the middle and high mountain area of southern Shaanxi, reaching 473,713.64 acres, accounting for 78.55% of the total cultivated land in this area. The restrictive factors of effective thickness of soil layer and soil organic matter content are widespread in the seven index areas. Soil organic matter content restriction exists mainly in the Guanzhong Weihe River Plain area, reaching 235,352.13 acres, whereas soil organic matter content restriction exists mainly in the Guanzhong Weihe River Plain area and the sandy area along the Great Wall of northern Shaanxi.

There were 34 combinations of the restrictive factors in Shaanxi, distributed over 928,896.20 hm^2, accounting for 23.23% of the total cultivated land. Among them, the combinations of fixed rate of irrigation/irrigation water source and soil organic matter content/fixed rate of irrigation are widely distributed. The area covered was 312,965.73 and 110,720.91 acres, respectively. Other distributions of combinations of restrictive factors are limited.

Except for the sandy area along the Great Wall of northern Shaanxi, single restrictive factors were predominant over the other six index areas (Table 4). The restrictive factor of fixed rate of irrigation/irrigation water source was predominant in the sandy area along the Great Wall of northern Shaanxi, covering an area of 312,965.73 acres, accounting for 42.19% of all cultivated land of the index area. The restrictive factor of terrain slope was predominant in the loess hilly and gully region of northern Shaanxi and the middle and high mountain area of southern Shaanxi, where the area reached 67.73% and 78.55% of each index area, respectively. The restrictive factor of effective thickness of soil layer was predominant in the low mountain plain district of southern Shaanxi and the Shangluo mountain hilly area, covering 38.10% and 50.19% of the index area, respectively.

The restrictive factor of soil organic matter content was predominant in Guanzhong Weihe River Plain area, reaching 35.85% of the whole cultivated land, whereas the restrictive factor of fixed rate of irrigation was predominant in the Weibei Loess Plateau area, accounting for 52.16% of the index area.

4.3 | Influence of restrictive factors of cultivated land

Geodetectors were used to explore the restrictive factors of each index area and their interaction. Due to limited space, only results of the sandy area along the Great Wall of northern Shaanxi (Table 5) and the difference test of the effects of different restrictive factors on cultivated land quality are presented in this paper (Table 6).

It can be seen from Table 5 that the effect of the two factors on the difference of cultivated land quality is stronger than that of the single factors. It can also be seen from Table 6 that in the sandy area along the Great Wall of northern Shaanxi, when the surface soil texture interacts with other restrictive factors, it shows great difference on the influence of spatial distribution of cultivated land quality.

According to Tables 5 and 6, the effect of a single factor and combined factors can be determined. Combined with the improvement potential of each grouping factor, the comprehensive improvement potential of the restrictive factors of cultivated land polygons can be calculated. According to the results of the statistical test of the geodetectors, the combination factors with no significant differences (95% level of significance) were eliminated in each index area. Finally, the improvement potential of each restrictive factor combination and the comprehensive improvement potential of each cultivated land plot were obtained. As the natural breakpoint method takes the discontinuous data as a basis for classification, according to the numerical statistical principles, this paper uses the natural breakpoint method in ARCGIS to classify the improvement potential value of the restrictive factors of cultivated land in Shaanxi (Figure 2; Feng, Wu, & Wang, 2012).

The overall improvement potential of the restrictive factors of the cultivated land was relatively low, and the trend was highly representative in the north and less representative in the south. The improvement potential of the low mountain plain district of southern Shaanxi and the middle and high mountain area of southern Shaanxi was generally low; with the exception of Weinan City, Guanzhong Weihe River Plain area and the Weibei Loess Plateau area remained low and relatively low, respectively. The cultivated land area of Guanzhong Weihe River Plain area was 1,143,382.67 acres, accounting for 28.60% of the total cultivated land in Shaanxi. High level of cultivated land was mainly concentrated in Guanzhong Weihe River Plain area, the major grain-producing area, where there is mild and wet weather and suitable water/heat conditions; the cultivated land quality is quite good, and therefore, room for improvement is limited.

Improvement potential of restrictive factors was significant in the loess hilly and gully region of northern Shaanxi and the sandy area along the Great Wall of northern Shaanxi. Wuqi County, located in the loess hilly and gully region of northern Shaanxi, and some of the counties part of Yulin City located in the sandy area along the Great Wall of northern Shaanxi have a great portion of cultivated land with average improvement potential. The cultivated land with relatively high improvement potential was mainly distributed in Dingbian County, Yulin City.

TABLE 5 Restrictive factor interaction exploration in the sandy area along the Great Wall of northern Shaanxi

	Surface soil texture	Soil organic matter content	Irrigation water source	Soil salination	Effective thickness of soil layer	Fixed rate of irrigation
Surface soil texture	0.0045					
Soil organic matter content	0.0595	0.0379				
Irrigation water source	0.9443	0.9441	0.9304			
Soil salination	0.0899	0.1443	0.9588	0.07083		
Effective thickness of soil layer	0.3585	0.3618	0.9664	0.3677	0.10169	
Fixed rate of irrigation	0.9430	0.9411	0.9347	0.9586	0.9681	0.9279

Note. Because some of the data are small, the table retains four decimal places.

TABLE 6 Difference test of the effects of different restrictive factors on cultivated land quality

	Surface soil texture	Soil organic matter content	Irrigation water source	Soil salination	Effective thickness of soil layer	Fixed rate of irrigation
Surface soil texture						
Soil organic matter content	Y					
Irrigation water source	Y	Y				
Soil salination	Y	N	N			
Effective thickness of soil layer	Y	Y	N	N		
Fixed rate of irrigation	Y	Y	N	Y	Y	

Note. "Y" signifies that when the two factors interact, the impact on the quality of cultivated land shows a degree of 95% significant difference. "N" signifies no significant difference.

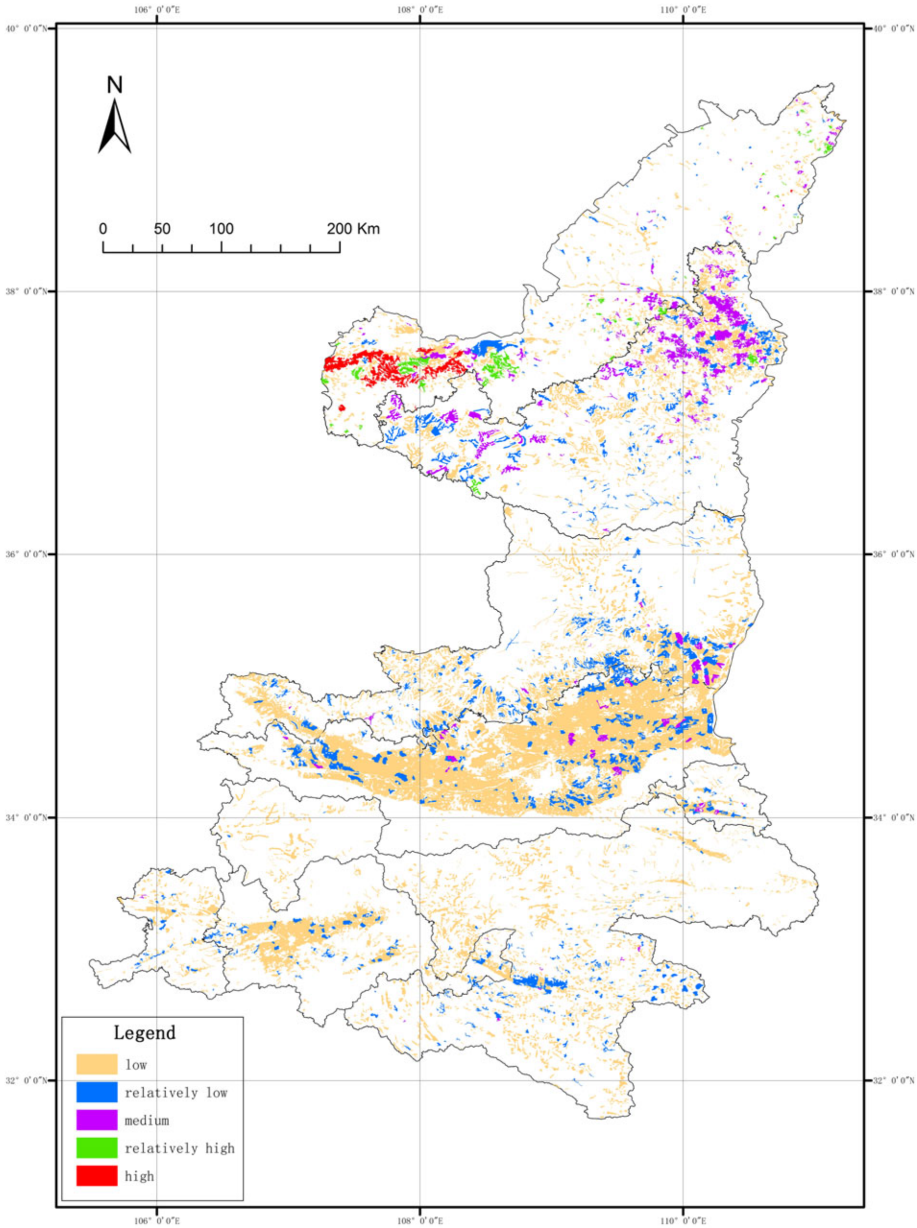

FIGURE 2 The comprehensive improvement potential of restrictive factors of cultivated land quality in Shaanxi Province [Colour figure can be viewed at wileyonlinelibrary.com]

4.4 | The improvement potential of cultivated land quality

According to the previous analysis, this paper used a single-factor and multifactor amelioration method in each index area to explore the land consolidation projects in Shaanxi and determine the potential value of the restrictive factors after improvement. The national natural grade index of the cultivated land after improvement using the classification results of agricultural land was then calculated and used to compare the changes in the national natural grade and national natural grade index. The cultivated land consolidation projects implemented in 1 year in Shaanxi were investigated. There were 221 cases overall. Because it is difficult to determine the direct reflection on the degree of improvement of the cultivated land quality after the majority of the cultivated land consolidation projects, we chose to use the grade and grade indices to represent the change of the cultivated land quality (Table 7). Finally, we used the differences to represent the improvement potential of cultivated land quality in Shaanxi (Figure 3).

The changes in cultivated land quality after some of the restrictive factors were improved are presented in Table 6. After a single-factor improvement, the improvement of cultivated land quality was limited, and the cultivated land quality did not significantly change. The cultivated land index changes depending on the restriction degree of the individual restrictive factors. For example, the terrain slope is a single strong restrictive factor in the loess hilly and gully region of northern Shaanxi. The grade index increases greatly after improvement. The irrigation restriction is not a strong factor in the loess hilly and gully region of northern Shaanxi. Although it can improve the quality by two degrees, the change is not obvious. Improving a combination of restrictive factors can promote the cultivated land quality significantly.

TABLE 7 The improvement of cultivated land quality after amelioration

Name	Polygon identifier	Restrictive type	Caption	87	88	89	91	92	93	94	95	National natural indicator index	National natural indicator
II	6595	87	Before	**5**	110	Loam	4	2	/	/	/	931.52	13
			After	**4**	110	Loam	4	2	/	/	/	1,045.22	13
I	4341	91	Before	1	140	Loam	**4**	2	Surface water	/	/	1,366.59	12
			After	1	140	Loam	**2**	2	Surface water	/	/	1,412.35	12
II	1937	92	Before	3	160	Loam	4	**4**	/	/	/	1,243.55	12
			After	3	160	Loam	4	**2**	/	/	/	1,406.27	12
VII	3537	95	Before	4	50	Sand	3	3	/	/	**The whole is sand**	2,212.28	10
			After	4	50	Sand	3	3	/	/	**Loam/sand/sand**	2,338.67	10
I	4730	91–92	Before	5	80	Loam	**4**	**4**	/	/	/	719.00	14
			After	5	80	Loam	**2**	**2**	/	/	/	953.28	13
VI	3028	88–91	Before	3	**40**	Sand	**4**	/	/	/	/	1,097.10	13
			After	3	**70**	Sand	**3**	/	/	/	/	1,183.09	13
III	4235	88–95	Before	2	**50**	/	4	/	3	3	**Loam/sand/sand**	1,496.33	12
			After	2	**90**	/	4	/	3	3	**Loam/sand/loam**	1,602.08	11
IV	6215	91	Before	1	80	Clay	**3**	1	Surface water	/	/	3,570.82	7
			After	1	80	Clay	**2**	1	Surface water	/	/	3,622.32	6
IV	8946	91–92	Before	1	100	Clay	**3**	**3**	Surface water	/	/	2,743.10	9
			After	1	100	Clay	**2**	**2**	Surface water	/	/	2,923.37	8
V	7728	88–92	Before	2	**80**	Clay	2	**3**	/	/	/	1,577.06	12
			After	2	**100**	Clay	2	**2**	/	/	/	1,613.30	11

Note. Assuming that other restrictive factors do not change, the quality of cultivated land after improvement changes as the dominant restrictive factor changes.

The amelioration of soil organic matter content/irrigation in the sandy area along the Great Wall of northern Shaanxi and effective thickness of soil layer/soil slope configuration in the Weibei Loess Plateau area can improve both the cultivated land grade and grade index.

According to Figure 3, there is significant diversity in the improvement potential of cultivated land quality after implementing the corresponding improvement measures to the restrictive factors. The potential of the sandy area along the Great Wall of northern Shaanxi and the loess hilly and gully region of northern Shaanxi is relatively high, with the low mountain plain district of southern Shaanxi and Guanzhong Weihe River Plain area the second highest. The potential of other index areas is generally low. The distribution of the improvement potential of cultivated land quality in Shaanxi Province is consistent with the distribution of the improvement potential of the restrictive factors, and the overall trend is high in the north and low in the south, which confirms the feasibility of the research method to a certain extent. This suggests that we can use the improvement potential of restrictive factors to represent the improvement potential of the cultivated land quality. Furthermore, in order to determine the change in cultivated land grade in the seven index areas, this paper used the average change situation to represent the diversity of the degree of improvement (Table 8).

According to Table 8, among the seven index areas, the average potential of cultivated land in the sandy area along the Great Wall of northern Shaanxi is the highest, with a value of 286.60. Therefore, this area can be regarded as the priority area of the Shaanxi Province land consolidation project and the key area for cultivated land quality improvement in Shaanxi Province. The loess hilly and gully region of northern Shaanxi, low mountain plain district of southern Shaanxi, Guanzhong Weihe River Plain area, and the middle and high mountain area of southern Shaanxi are next in importance, in decreasing order. The potential of the Weibei Loess Plateau area and Shangluo mountain hilly area is relatively low.

Therefore, according to the results obtained in this study, combined with the actual potential of each index area and the main restrictive factors, the following targeted approaches can be taken to improve the overall cultivated land quality in Shaanxi.

1. The sandy area along the Great Wall of northern Shaanxi and Weibei Loess Plateau area are the main limitations for irrigation, whereas the sandy area along the Great Wall of northern Shaanxi is the area where total rainfall is the least; to solve these irrigation restrictions, the water source project and the water delivery project must be improved. According to the actual situation, a water reserve and delivery project with full utilization of rainwater, surface water, and a small amount of shallow groundwater for farmland irrigation can be built in the Weibei Loess Plateau area.
2. The main restrictive factor in the Guanzhong Weihe River Plain area is soil organic matter content. The combination of cultivated land, deep ploughing, and straw returning to soil will greatly improve the content of organic matter in the soil, promote soil maturation, improve soil water storage and fertilizer capacity, and improve the quality of the cultivated land comprehensively.
3. The main restrictive factor in the loess hilly and gully region of northern Shaanxi and the middle and high mountain area of southern Shaanxi is the terrain slope. In the implementation of specific land consolidation projects, the actual situation in the location must be fully taken into account, making sure the project suits the local conditions. The project must be targeted to ensure planning and design reflect the regional differences and maintain operability. By implementing a land levelling project, as well as

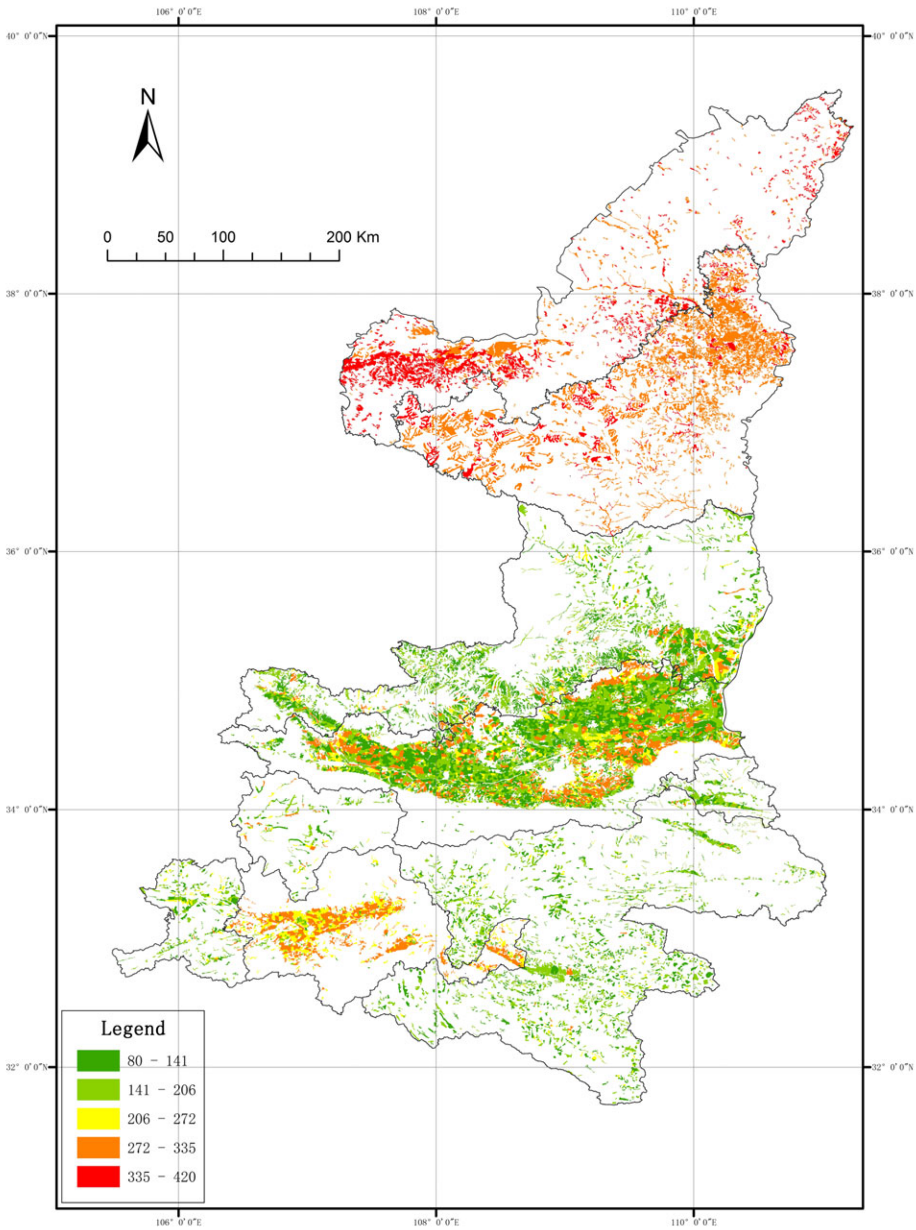

FIGURE 3 Distribution of the improvement potential of the cultivated land quality in Shaanxi Province [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 8 Cultivated land quality change in the seven indicator areas in Shaanxi

Name	Average index before	Average level before	Average index after	Average level after	Improvement value
I	740.70	14	1,027.30	13	286.60
II	702.82	14	910.30	13	207.48
III	1,280.34	12	1,361.17	12	80.83
IV	2,774.58	9	2,928.39	8	153.81
V	1,083.22	13	1,169.32	12	86.09
VI	1,248.07	12	1,391.64	12	143.58
VII	2,304.96	10	2,490.22	9	185.27

through local levelling or slope change ladder projects according to the specific terrain slope, the size and slope of land plots can meet the irrigation requirements.

4. The mountain in the low mountain plain district of southern Shaanxi has gently sloping sides. There are more slopes and less valleys and mountain basins in the Shangluo mountain hilly area,

and therefore, the cultivated land quality is highly influenced by the effective thickness of the soil layer. Tillage, or the transfer of soil by cultivation, refers to the high-quality cultivation of the soil layer, such as by peeling, transfer, and reuse. Tillage stripping technology is a new development project in China in recent years in activities such as land management, cultivated land protection, construction land control, and agricultural production. In the construction of occupied high-quality cultivated land, where cultivating the land results in greater soil peeling, land with a peel thickness of 20 cm or more transferred to the soil is considered a relatively low-quality area.

5 | DISCUSSION

At present, in the study of restrictive factors of cultivated land quality, there has been no quantitative analysis of the influence degree of the restrictive factor combinations. In this paper, the method of geodetector is introduced to determine the influence degree of restrictive factors on cultivated land quality. However, the geodetectors can only reveal the change of the influence degree of the factors after the interaction of two factors and still have some limitations application on multifactor combination types. Therefore, the quantitative method of the influence degree of the restrictive factors should be the future focus for research.

In this paper, the provincial aggregate data of the results of cultivated land quality classification in Shaanxi Province were used to illustrate the research ideas for cultivated land quality improvement in the provincial areas on the basis of the reduction of restrictive factors. The provincial land plots were obtained by the multiattribute clustering method at the county level, which can reflect the distribution of the restrictive factors of the whole cultivated land. However, in practical applications, whether the restrictive factors can be matched to the specific plots should be further verified. Whether the provincial unit can replace the county-level unit to be the basic units for research on the restrictive factors is our future research objective.

The sensitivity of the restrictive factors was less considered in this study. In future, the choice of restrictive factors should continue to be analysed considering different aspects. In order to be able to guide specific land consolidation projects, each index area should be studied in detail.

6 | CONCLUSION

On the basis of the results of cultivated land quality classification, this paper introduces the geodetector and analyses the restrictive factors of cultivated land quality, the potential of cultivated land quality improvement in Shaanxi Province, and the restrictive factors in different index areas. The following conclusions were drawn:

1. There are 46 combinations of restrictive factors, of which 12 are single-factor and 34 are double-factor restrictions. The restrictive factors of cultivated land quality in Shaanxi are mainly terrain slope, effective thickness of soil layer, and soil organic matter content, which are single factor. The cultivated land area under single-factor restriction reaches 76.77% of the total cultivated land area. Irrigation water source/fixed rate of irrigation, soil organic matter content/irrigation water source, and effective thickness of soil layer/soil organic matter content are among the combinations of the restrictive factors. The single restrictive factor of the terrain slope is the most widespread, accounting for 25.81% of the total cultivated land area. The most widespread combination of the restrictive factors is the irrigation water source/fixed rate of irrigation.
2. The potential of cultivated land quality improvement in Shaanxi Province is low, and the potential of cultivated land quality improvement in northern Shaanxi is high. The low mountain plain district of southern Shaanxi, the middle and high mountain area of southern Shaanxi, the Guanzhong Weihe River Plain area, and the Weibei Loess Plateau area are located in the south of Shaanxi. In addition to some counties of Weinan City having a moderate improvement potential of cultivated land quality, the other areas have low and relatively low levels of improvement potential. The loess hilly and gully region of northern Shaanxi and the sandy area along the Great Wall of northern Shaanxi are located to the north of Shaanxi. Their improvement potential of cultivated land quality surpasses that of the other areas significantly. After amelioration of the restrictive factors, the national natural grade index of the sandy area along the Great Wall of northern Shaanxi increased by 286.60, making it the highest in Shaanxi. Although the area is low in precipitation, the temperature is low, light is abundant, the light energy is rich in resources, and a project to improve the quality of the cultivated land has been adopted in the area.
3. Geological detectors can scientifically quantify the extent of the impacts of various combinations of restrictive factors on the quality of cultivated land, and the potential of restrictive factors can represent the potential of cultivated land quality to a certain extent. According to the results of this study, the improvement potential of the restrictive factors and the potential of improving the quality of cultivated land are similar, which shows that improvement of the restrictive factors can fundamentally reflect improvement of cultivated land quality. The quantification of the combination of restrictive factors by using geological detectors further strengthens the study, and the exploration results can be used to distinguish the single restrictive factors and the stronger restrictive factors from the combination of restrictive factors, which can help to improve the selection of the improvement measures.
4. The effect of single-factor improvement on cultivated land quality has some limitations, and the combination of restrictive factor improvement significantly improved cultivated land quality. According to the study results, areas with single restrictive factors in the loess hilly and gully region of northern Shaanxi, the middle and high mountain area of southern Shaanxi, and the Shangluo mountain hilly area encompass more than 50% of the regional cultivated land. It is suggested that improving the single restrictive factors in these areas should be based on the actual situation. The specific restrictive factor combination model should also be improved according to the actual situation.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest. The sponsors of this work had no role in the design of the study, data collection, analysis, or interpretation, writing of the manuscript, or the decision to publish the results.

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